PDHengineer.com

Course № EN-4021

Introduction to Separation of Oil and Water

This document is the course text. You may review this material at your leisure before or after you purchase the course. If you have not already purchased the course, you may do so now by returning to the course overview page located at:

http://www.pdhengineer.com/pages/M-4023.htm
(Please be sure to capitalize and use dash as shown above.)

Once the course has been purchased, you can easily return to the course overview, course document and quiz from PDHengineer's My Account menu.

If you have any questions or concerns, remember you can contact us by using the Live Support Chat link located on any of our web pages, by email at administrator@PDHengineer.com or by telephone toll-free at 1-877-PDHengineer.

Thank you for choosing PDHengineer.com.

PDHengineer.COM
Continuing Education for Engineers
17350 State Highway 249 | Suite 140 | Houston, TX 77064

INTRODUCTION TO SEPARATION OF OIL AND WATER

by Kirby S. Mohr. P.E.

Mohr Separations Research, Inc.
Jenks, Oklahoma, USA
Website: oilandwaterseparator.com
918-299-9290

INTRODUCTION TO SEPARATION OF OIL AND WATER

by Kirby S. Mohr. P.E.

Mohr Separations Research, Inc.
Jenks, Oklahoma, USA
Website: oilandwaterseparator.com
918-299-9290

INTRODUCTION:

In refineries, chemical plants, electric power plants and many other industrial facilities the separation of various oil and water mixtures can cause problems. These problems are often the result of imperfect understanding of the nature of the mixtures and how to take advantage of their properties to accomplish the required separations.

In addition, many states and cities require treatment of stormwater from parking lots and other facilities where cars and trucks may be present to treat stormwater to ensure the oil and fuel that may have leaked from the vehicles does not enter the rivers, streams and lakes.

This course will give an overview of many of the industrial and also stormwater processing situations that may arise and also some of the means for solving the problems with pros and cons of many possible designs as well as some suggestions on determining the nature and extent of the problems and possible solutions. For purposes of this discussion, oil means hydrocarbons except where specifically noted otherwise.

TYPES OF SEPARATIONS:

Four main types of separations are likely in industrial plants and numerous more similar situations exist from time to time. The four most common are:

Water from Oil where main flow is *Mostly Oil*
Oil from Water where main flow is *Mostly Water*
Emulsions
Non-Hydrocarbon oils

WATER FROM OIL WHERE MAIN FLOW IS *MOSTLY OIL*

Separating water from continuous flows of oil is commonly required in oil production applications, oil refineries and chemical plants as well as some places where it is essential that the hydrocarbons not be contaminated with water. The possible problems with water contamination were first emphasized during the last part of World War II when it was found that airplanes could fly high enough to cause the water to freeze in the fuel lines. The pilots found this unreasonably inconvenient because it caused the engines to stop, so equipment was designed to ensure that only tiny amounts of water were allowed to remain in the aviation fuel.

It was also found that refinery processes operated easier and better and corrosion problems were avoided by removing the water from the hydrocarbons.

Numerous types of equipment have been designed to cope with the widely varying problems of removing the water from the oil and several of these are discussed below. The problems in removing water from oil vary widely mostly because of the widely varying viscosity of hydrocarbons that must be treated.

OIL FROM WATER WHERE MAIN FLOW IS *MOSTLY WATER*

Separating oil from a continuous stream of water is commonly done in oil refineries, chemical plants, and other industrial facilities for resource recovery as well as environmental reasons. It is also practiced in some oil field situations where the flow from the wells is primarily water. The beginnings of the application of scientific principles to these separations began in 1948 when the American Petroleum Institute (API) commissioned a study by the University of Wisconsin to prepare a method for designing separators to recover oil from the main refinery wastewater streams. This design is still used, but it was not originally designed for environmental purposes and does not generally produce an effluent suitable for discharge to rivers, streams or lakes. This method requires a large residence time and is therefore bulky and costly, so modified design “API Type” systems are often used.

Since the 1948 study[2], numerous designs have been used to remove oil from water and several are discussed below. The newer designs make it possible to remove oil from the water down to less than 10 mg/l.

EMULSIONS:

An emulsion is a mechanical mixture, not a solution, consisting of droplets of one immiscible fluid dispersed in another continuous fluid. A good definition, offered by [10], is: "An emulsion is an apparently homogenous mixture in which one liquid is dispersed as droplets throughout a second immiscible liquid." In the case of water and oil, two types of emulsion are common, depending on which is the continuous phase.

1. Oil in water emulsions.
2. Water in oil emulsions.

A third type, water in oil in water, is possible but very uncommon.

Emulsions can be very difficult to separate and because of the extreme variations in type, causes, and treatment are outside the scope of this discussion.

NON-HYDROCARBON OILS

INTRODUCTION TO SEPARATION OF OIL AND WATER

by Kirby S. Mohr. P.E.

The recent interest in renewable fuels has revived interest in vegetable oils as fuels, especially as biodiesel. The vegetable oil and biodiesel systems present different problems in making the separation between the aqueous and non-aqueous phases. This separation is complicated by the relatively high viscosity of most vegetable oils and solubility issues in biodiesel production facilities. The systems required for these separations are substantially different from systems used in conventional hydrocarbon oils and are outside the scope of this discussion.

INTRODUCTION TO THEORY OF OIL WATER SEPARATION

Oil and water may relatively conveniently separate using gravity and various enhanced gravity systems. In the case of removing oil from water, droplets of oil rise within the water and in removing water from oil, water droplets fall within the oil.

In cases where the continuous phase is oil, it may be advisable to apply additional force to help force the water to separate. In electrostatic desalters and treaters, an electrical field is applied and in coalescing cartridge separators the use of tightly packed fiber beds are used. These situations are discussed in the appropriate sections below; gravity and enhanced gravity separations are discussed directly following:

Settling of Particles in a Gravity Separator

The settling of solids particles in a clarifier or other settling device, is governed by Stokes's Law[16]. This function, simply stated, is:

$$Vp = \frac{G}{(18x\mu)} x(d_p - d_c)x D^2$$

Where: V_p = droplet settling velocity, cm/sec
G = gravitational constant, 980 cm/sec^2
μ = absolute viscosity of continuous fluid, poise
d_p = density of particle (droplet), gm/cm^3
d_c = density of continuous fluid, gm/cm^3
D = diameter of particle, cm

Since the equation was developed for solids falling, a particle (or droplet) rise velocity is a negative number. Assumptions Stokes made in this calculation are:

1) Particles are spherical
2) Particles are the same size
3) Flow is laminar, both horizontally and vertically

From the above equation it may be seen that the most important variables are the viscosity of the continuous liquid, specific gravity difference between the continuous liquid and the particle, and the particle size. After these are known, the settling velocity and therefore the size of separator required may be calculated.

The velocity of settling or rising is dependent on the hydrodynamic drag exerted on the settling particle by the continuous fluid. This drag is dependent on the shape of the particle as well as the viscosity of the continuous fluid. This is the same sort of situation that is found in other cases where a falling object has a high surface area/mass ratio. In a vacuum, a feather falls at the same rate as a lead ball. In air or any other resistant media the ball will fall faster due to the air resistance against the feather. The same sort of phenomenon governs the settling of solid particles in a clarifier or other liquid-containing vessel. They do not perfectly obey Stokes's Law because of their particle shape.

The pure Stokes's Law calculation depends on knowing the particle size and assuming that it does not change. Solid particles flocculate into larger particles of irregular shape that settle somewhat like snowflakes.

The use of Stokes's Law described above is a very simplified version of the calculations required for determining clarifier sizing. More rigorous calculations are required to take care of such functions as hindered settling. These calculations are treated extensively in Montgomery[9]. In considering the rise of oil droplets in water or the fall of water droplets in oil, it is necessary to consider that the droplets are not a single size, but rather a continuously changing spectrum of droplet sizes. For this reason, if it is desired to predict the performance of a separator the spectrum of droplet sizes must be considered.

Rising of Oil Droplets

Separation of oil and water is different than the settling separation of solids in a clarifier. Oil droplets coalesce into larger, spherical droplets, while solids agglomerate into larger masses but do not coalesce into particles that have lower surface/volume ratios like oil.

The rise rate of oil droplets is also governed by Stokes's law. If the droplet size, specific gravity, and continuous liquid viscosity are known, the rise rate and therefore the required vessel size may be calculated.

To calculate the size of an empty-vessel gravity separator, it is first necessary to calculate by the use of Stokes's Law the rise velocity of the oil droplets. The size of the separator is then calculated by considering the path of a droplet entering at the bottom of one end of the separator and exiting from the other end of the separator. Sufficient volume must be provided in the separator so that the oil droplet entering the separator at the bottom of the separator has time to rise to the surface before the water carrying the droplet exits the opposite end of the separator.

Calculation of rise rate by this method is a gross simplification of actual conditions because oil droplets are not all the same size, and they tend to coalesce into larger droplets. Large droplets exhibit trailing tails much like raindrops. The tails are due to the droplet being distorted by the hydrodynamic drag noted above.

Droplet rise follows Stokes's law so long as laminar flow conditions prevail. Laminar flow regimes (in the direction of rise) prevail with small droplets. The rise rate of larger droplets may exceed the velocity of laminar flow, in which case flow begins to be turbulent. Particles of this size and larger do not rise as rapidly as would be expected from Stokes's law. When the droplets coalesce, they do not form flocs but become larger droplets. Interfacial tension (sometimes referred to as surface tension) of the liquid tends to make the droplets assume spherical shapes since this is the smallest possible shape for a given mass.

The Stokes's Law calculation is accurate for oil drop rise in the same way that it is accurate for solids settling – only if the particle size and continuous liquid viscosity are accurately known. The problems with this calculation are therefore:

1. What is the particle size?
2. What is viscosity of the continuous liquid?

The viscosity of the continuous liquid is readily obtained from literature data in the case of water and measurable in the case of oils.. The design of such separators usually requires design over a wide variety of temperatures (and therefore viscosities) to account for summer and winter conditions as well as possible process upsets, so several viscosities may be considered during design.

The droplet size is much more difficult to determine. Particle sizes of solid particles are fairly easy to determine in the laboratory, but oil droplet size information is much more difficult to obtain. One tedious way to determine oil droplet sizes is to take a microscopic photograph of droplets in water and count the various size droplets. Other methods have been used with varying success, as noted by Rommel, et al[13]and Au, et al.[3]. These include use of particle counters such as electric sensing zone particle counters.

It might be possible, with ultrasonic or other methods of dispersion, to generate quantities of oil droplets of generally equal size, but the droplets encountered in normal field operation vary widely in size from particles less than 5 microns[12] to the great quantities of oil found in major oil spills.

If the droplet size is not known, or a large range of droplet sizes is present (the normal situation), how then is it possible to determine the rise rates of the droplets and therefore the size separator required?

Because the volume of oil in a droplet is proportional to the cube of the diameter, it follows that very small droplets contain extraordinarily small quantities of oil. We may therefore confine ourselves to the examination of oil droplets large enough that the quantity of oil represented by them may cause environmental problems if discharged into surface or subsurface waters. Oil should not be present in quantities great enough to cause oil sheens or even in the small quantities required to show more than 15 ppm on the standard EPA tests. Many jurisdictions, including King County, WA (Seattle)[12] have enacted standards allowing discharge oil levels considerably less than the EPA limit of 15 ppm oil and grease in the water discharged. In order to minimize the possibility of such discharge, it is wise to proceed carefully and cautiously in the design of oil-water separator systems.

NON-DISSOLVED vs. DISSOLVED OILS

In general, all separators deal only with non-dissolved oils. Most hydrocarbons have very limited solubility in water, but certain aromatics such as Benzene have substantial solubility and this must be taken into account in designing equipment where these chemicals may be present. If these are present, some other means of removing them such as distillation may be considered.

WATER FROM OIL SEPARATORS

TWO AND THREE PHASE SEPARATORS

Two and three phase separators are often used in oil production and refining systems and in chemical plants. They are usually mostly empty vessels, sized based on empirical relationships and often provided with rudimentary baffles and / or mesh pads for mist elimination and heating arrangements to raise the temperature of the oil, thus decreasing the viscosity and aiding the separation.

Two phase separators may be used where only oil and gas are present with no aqueous phase or in situations where only small amounts of gas or no gas are present with the aqueous and hydrocarbon phases. They are also often known as “free water knockout drums” and may be designed either as vertical or horizontal vessels. High pressure systems may be designed as spheres because this is the most economical shape to manufacture in a high pressure design.

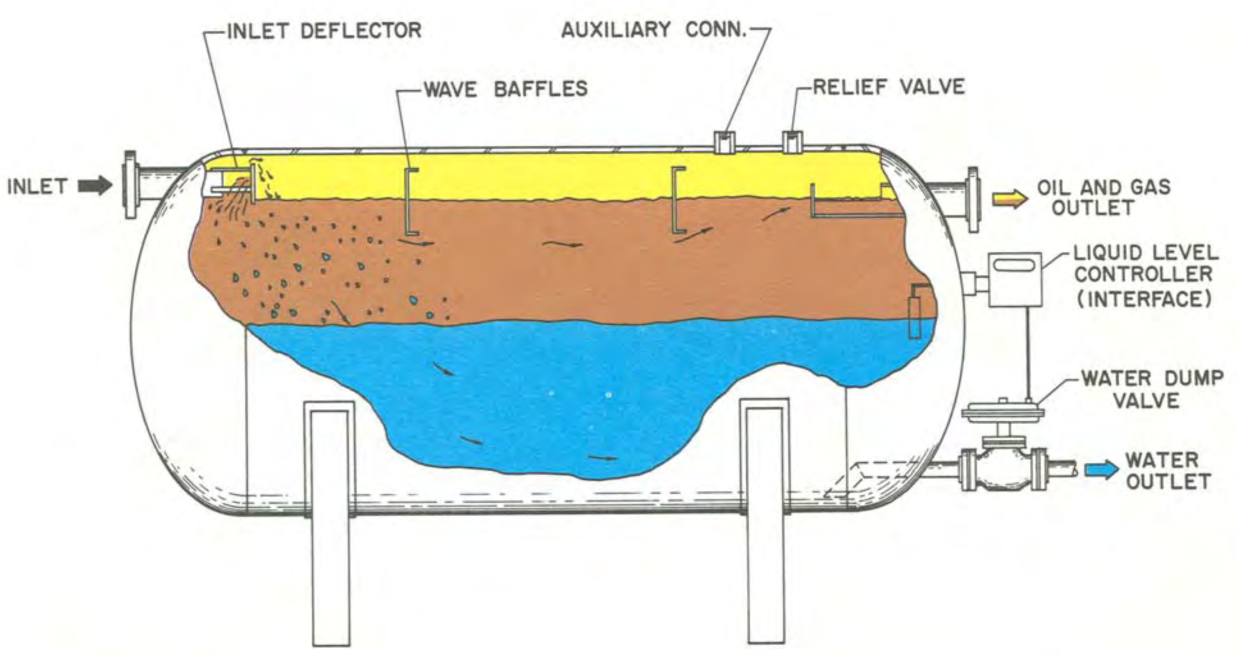

Figure 2: Free Water Knockout (two phase separator)
Source: Smith[14]

Three phase separators are similar to two phase separators except that they are provided with connections for water, oil and gas drawoff. Several general designs have been used; the one shown below is typical of oil field practice. Three phase separators are commonly heated as well, with heat being derived from burning some of the gas in the incoming stream.

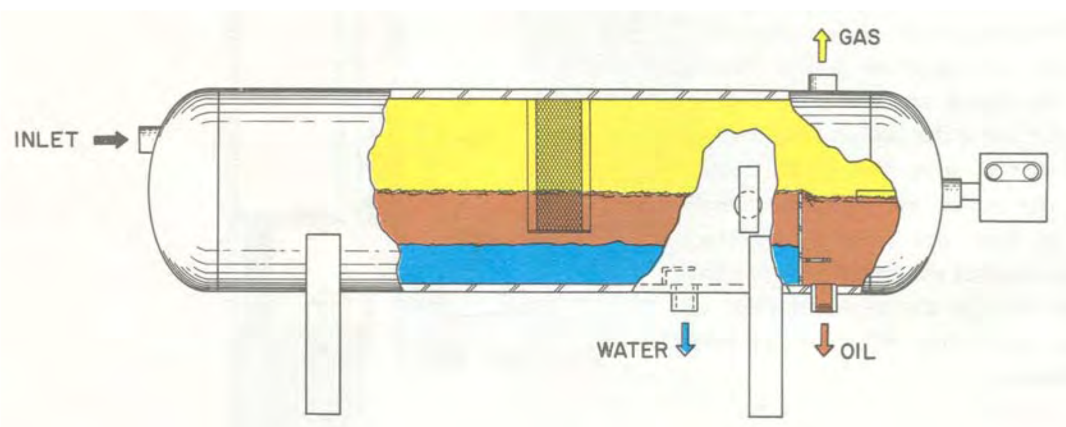

Figure 2: Three Phase Separator
Source: Smith[14]

ELECTROSTATIC TREATERS AND DESALTERS

The electrostatic desalter / treater process involves the creation of a high voltage electric field through which the crude must flow from the entrance header below the electrodes to the exit header in the top of the vessel. The small water droplets in the crude are coalesced in the electric field into large droplets which fall rapidly to the interface level removing entrained salt and speeding up the settling rate of the water phase.

In the unit high voltage is applied to one of two sets of steel Electrode grids in the vessel. These two sets of grids are parallel to the horizontal center line of the vessel. The lower grid (hot grid) is located near the center line of the vessel and is charged with the secondary voltage or the transformer (high voltage). This grid is suspended from an insulated support frame.[8]

The upper grid is anchored to the vessel wall through the support beam and serves as a ground grid.

The flow rate determines the required retention time in the electric field. When this rate is increased much beyond the capacity of the unit, the coalesced droplets cannot settle out and some solid particles and/or water may carry over into the product.

Desalters and treaters differ in that desalters usually are provided with additional water beyond what is naturally entrained in the oil flow and treaters are not. This is because the basic function of a treater is to remove the water that is present and the basic function of the desalter is to remove the salts present by dissolving them in water and removing the water. The salts are removed because they cause corrosion problems downstream in the refinery.

COALESCING CARTRIDGE SEPARATORS

Coalescing Cartridge separators are generally of two types:

- Packed separators, often called “hay packed”
- Filter cartridge separators

Packed Separators:

The packed type separators were first developed at the end of World War II for treatment of aviation gasoline to remove water. The term “hay pack” is really misleading because the material often used is excelsior (shredded wood) and not hay. The media is a densely packed bale of fibrous material such as the excelsior, stainless shavings, Teflon shavings or other fibrous material.

These systems generally include one or more bales of media in a horizontal pressure vessel and operate by providing a surface for the aqueous phase to accumulate on and by causing generally laminar flow to allow some settling time without channeling. The hydrocarbons flow horizontally through the vessel and as this is occurring, the aqueous phase accumulates on and in the packs and forms large droplets which drain down to the bottom of the vessel and are removed there. Figure 3 below shows a typical configuration of this type media.

Figure 3: Coalescing "Hay Pack" constructed of excelsior wood shavings.
(Note: Shown placed on end: support wheel on end would be vertical when installed)

While excelsior type products are effective to a degree in achieving the desired results some problems and limitations are encountered. Excelsior has a limited life span in that, being organic, it will decompose. Excelsior, or any equivalent natural or synthetic fibrous type material, has a tendency to clog easily with dirt, debris, and other contamination so that, in many instances, frequent replacement is required. The results of clogging due to collection of debris and contaminants tends to cause the fluid to channel, that is, the fluid flows through the filter media in small channels so that only a relatively small percent of the filter medium is actually effectively utilized. Another difficulty with the use of excelsior and similar configured natural and synthetic materials is that such materials are, by their nature, randomly oriented, having no preferential direction of inclination of elongated components. For this reason water droplets coalescing on such material are not *preferentially* downwardly oriented in their flow path, and therefore droplets can detach from horizontal portions of the filter medium and become resuspended in the fluid stream.

FILTER CARTRIDGE SEPARATORS:

Filter cartridge type separators are often used in treating refined petroleum products to remove water generated as part of the processing or acquired during time in pipelines or tankage. The cartridges used are generally composed of a dense fiberglass mat held together with a phenolic plastic binder and are used in conjunction with a screen separator cartridge of a hydrophobic nature. The flow is commonly from inside to outside in the coalescing cartridge and outside to inside in the separator cartridge. The water drops are coalesced into large drops in the coalescer cartridge and are barred from exiting the filter vessel with the hydrocarbons by the separator cartridge. Because the coalescer cartridges are very dense they are also fine filter cartridges and tend to plug easily (much more easily than the packing described above or other methods of separation). For this reason they are only used where excellent water removal is necessary and few or no solid particles are present. Common applications are treating jet fuel, gasoline, or kerosene for water removal.   Figure 4 below shows a schematic of the operation of a typical coalescer / separator system.

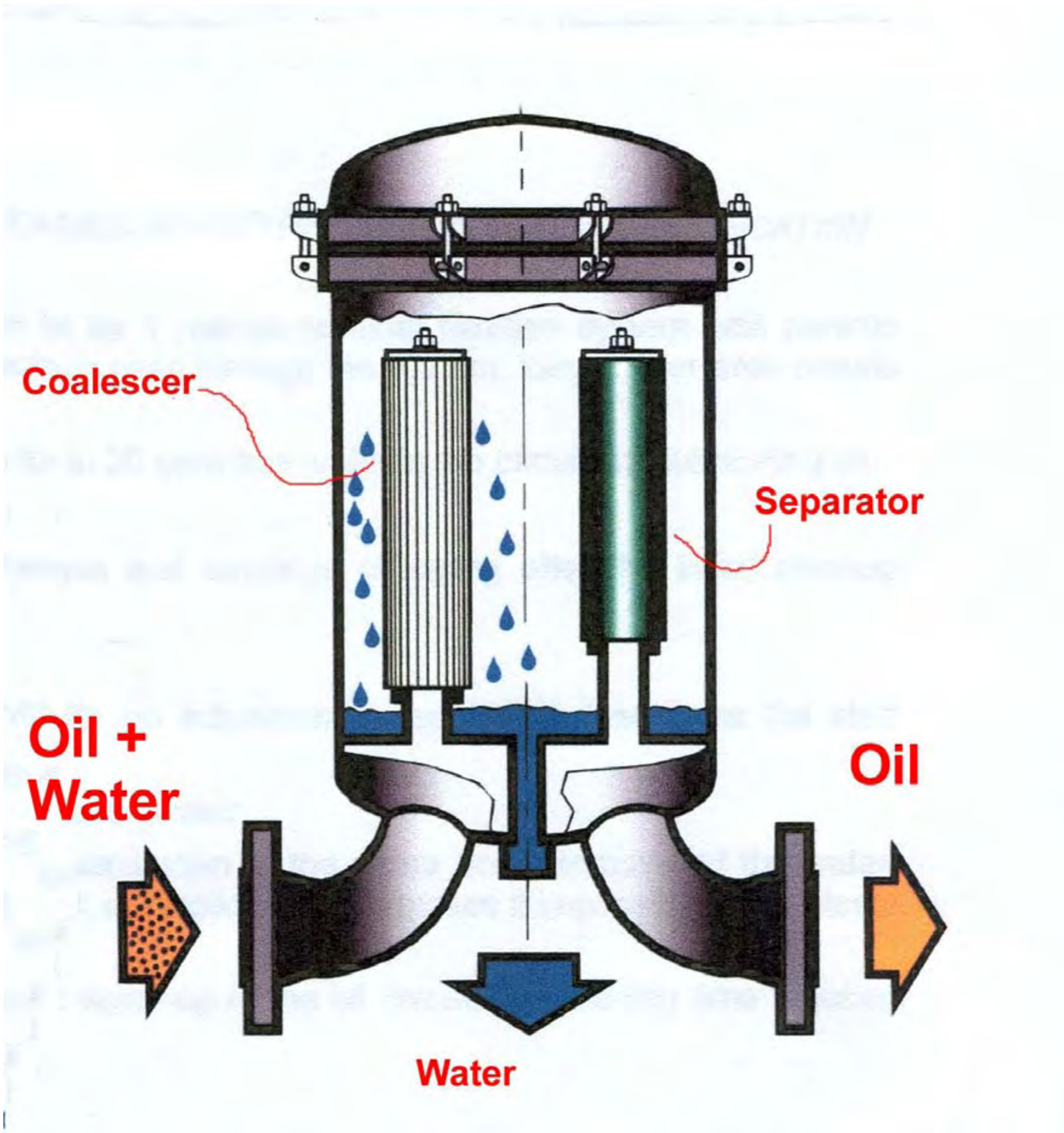

Figure 4: Cartridge type Water Removal System
Note: typical for treating aviation fuels.

ABSORBENT SEPARATORS

Absorbents are often used as a final treatment stage in the use of hydrocarbons such as jet fuel or gasoline. Referring to them as "separators" is a misnomer because they do not separate and remove the water they only sequester it so that it cannot pass downstream to the automobile or airplane. They are compact and easily mounted on a fueling truck, but are a very expensive way to remove water from hydrocarbons and are only used where absolutely necessary.

Legal Aspects

In general, water is only removed from oil and other hydrocarbons in an industrial setting and there is limited or no discharge to the environment, so the only legal aspects of treating oil to remove water are the safety aspects (OSHA, etc.) and possible legal aspects of discharge of the water. For this reason, the following only deals with the legal aspects of removing oil from water.

Oil in water discharges from industrial and other facilities are governed by a variety of federal, state and local laws. Included are the Clean Water Act (CWA) and its amendments, the Oil Pollution Act of 1990, the Coastal Zone Management Act and others [5].

Most hydrocarbon wastes are not covered by the Resource Conservation and Recovery Act of 1976 and its amendments (RCRA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) also known as the Superfund Act[5]. These wastes, produced by the extraction, transportation, refining, or processing of oil and natural gas, are specifically exempted from being regulated as "hazardous wastes" under any other laws.

The basic law covering discharges is the Clean Water Act. It was originally enacted as the Federal Water Pollution Control Act of 1972, but was amended extensively in 1977. The 1977 amendments, in conjunction with the earlier legislation, became known as the Clean Water Act. Under the terms of this Act, amended Section 402 created the National Pollutant Discharge Elimination System (NPDES) permit system. Permits for point sources under this system are granted by the Environmental Protection Agency (EPA) or by states with EPA approved programs. After enactment of this law, any discharges other than those covered by the permit are illegal. Although the Clean Water Act was enacted primarily to control discharges from Publicly Owned Treatment Works (Sanitary Sewer Plants) and toxic discharges from industrial plants, it also controls discharges of petroleum and other hydrocarbons into the waters of the United States.

Most states and localities require discharges to contain 15 ppm or less oil and grease, based on a 24 hour composite sample. Oil and grease may include petroleum hydrocarbons as well as animal and vegetable oils. Some localities have established lower discharge limits. King County, Washington, which includes the Seattle area, requires discharges to be less than 10 ppm[12].

Also important are the new stormwater management rules published by the EPA in 1990 (NPDES Permit Application Regulations for Storm Water Discharges; Final Rule, 1990). The reasoning behind stringent regulation of stormwater is included in the "National Water

Quality Inventory, 1988 Report to Congress", as discussed in the Federal Register, November 16, 1990. This report concludes that "pollution from diffuse sources, such as runoff from agricultural, urban areas, construction sites, land disposal, and resource extraction is cited by the States as the leading cause of water quality impairment." These sources appear to gain in importance as discharges of industrial process wastewaters and municipal sewage plants come under increased control. A study conducted by the Huron River Pollution Abatement Program (Federal Register, November 16, 1990) detected illicit discharges to storm sewers at a rate of 60% (of the number of businesses surveyed) in businesses related to auto- mobiles such as auto dealerships, service stations and body shops. This study noted that most of these discharges to the sewer had been legal when installed.

Stormwater discharges were covered under the CWA but not required to have permits under the NPDES system until the final rules were published in the Federal Register, November 16, 1990. "Stormwater discharges" refer to discharges consisting entirely of rainwater runoff, snowmelt runoff, or surface runoff and drainage. Waters that do not meet this definition are not covered by these regulations. The new rules specify that facilities with stormwater discharges from "areas containing raw materials, intermediate products, finished products, by-product, or waste product located on site" will require a NPDES permit. Several categories of facility are specifically exempt from these regulations, notably stormwater runoff from mining operations, oil and gas exploration, production, processing, or treatment operations, and parking lots whose rainwater sewers are not interconnected with manufacturing facility sewers.

It should be noted that the above concerns mostly legal aspects of discharging waters directly to rivers and streams. If it is desired to discharge the water to a sanitary sewer, different rules apply:

DISCHARGE TO SANITARY SEWER (PRETREATMENT)

Sanitary sewer authorities are under the same requirements as other dischargers to the waters of the US: They must meet the requirements of the Clean Water Act. In addition, these authorities must also meet the requirement of the Clean Air Act (industrial dischargers do too, but their discharges to air are not directly tied to the water quality as are the sanitary sewer plants). To meet their air discharge permit requirements, most sanitary sewer authorities require industrial discharge to the sanitary sewer to have a maximum oil content. The allowable amounts vary, but are often about 100 mg/l oil in the water.

Many industrial plants choose to discharge their wastewater to sanitary sewer because the regulatory paperwork requirements are less. If it is desired to make such a discharge, the local authorities must be consulted to determine their requirements for discharge quality and monitoring. Technical solutions to problems with discharge to sanitary sewer are much the same as solutions to discharge to surface water, but may be easier to implement because of (usually) higher discharge limits.

SYSTEMS AVAILABLE FOR REMOVING OIL FROM WATER

Systems for removing oil from water range from very simple holding ponds with or without skimming arrangements to very elaborate membrane technology-based systems. For most applications in removing oil, the simplest systems are often inadequate (although often used) and the most complicated are either too expensive or too maintenance-intensive. Most of the following discussion, therefore, will concentrate on methods of separation intended to meet regulatory requirements with minimum cost and maintenance.

Gravity Separation

The simplest possible separator is an empty chamber with enough volume to contain spills. A typical spill control separator is shown in Figure 5[12]. A spill control separator is too small to intercept small droplets and is only suitable for intercepting spills of oil or grease. Spill control separators are only effective if any accumulated oil is removed regularly. If the oil is not removed regularly, a storm may flush the accumulated oil out of the separator into the downstream sewer.

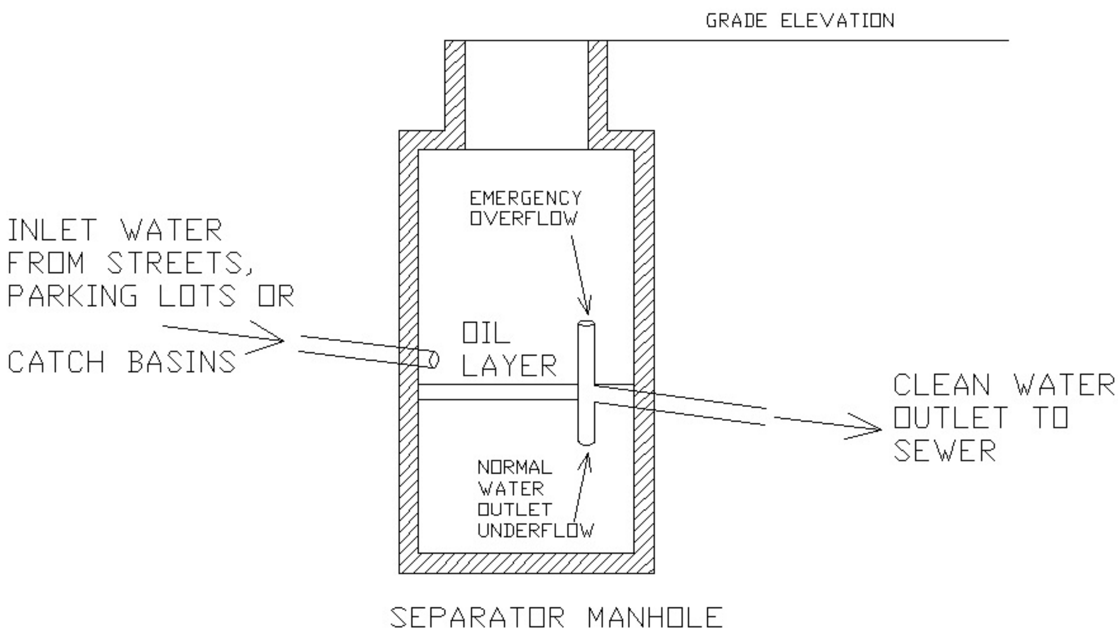

Figure 5: Spill Control Manhole

API separators are gravity type separators similar to spill control separators, but are generally larger, more sophisticated, more effective, and are usually equipped with oil removal facilities. The American Petroleum Institute (API) provides design criteria for oil-water separators. A design method is provided in the API Manual on Disposal of Refinery Wastes, Chapters 5 and 6- Oil-Water Separator Process Design and Construction Details

[1]. API separators are extensively used in oil refineries and chemical processing facilities where waters containing relatively large amounts of oil are present and need to be processed to meet the requirements of NPDES permits. A diagram of a typical API separator is shown in Figure 6 (Adapted from API Publication 421, 1990). It should be noted that this same API publication contains a survey of refinery API separators that indicate most of them do not meet the requirements of the Clean Water Act.

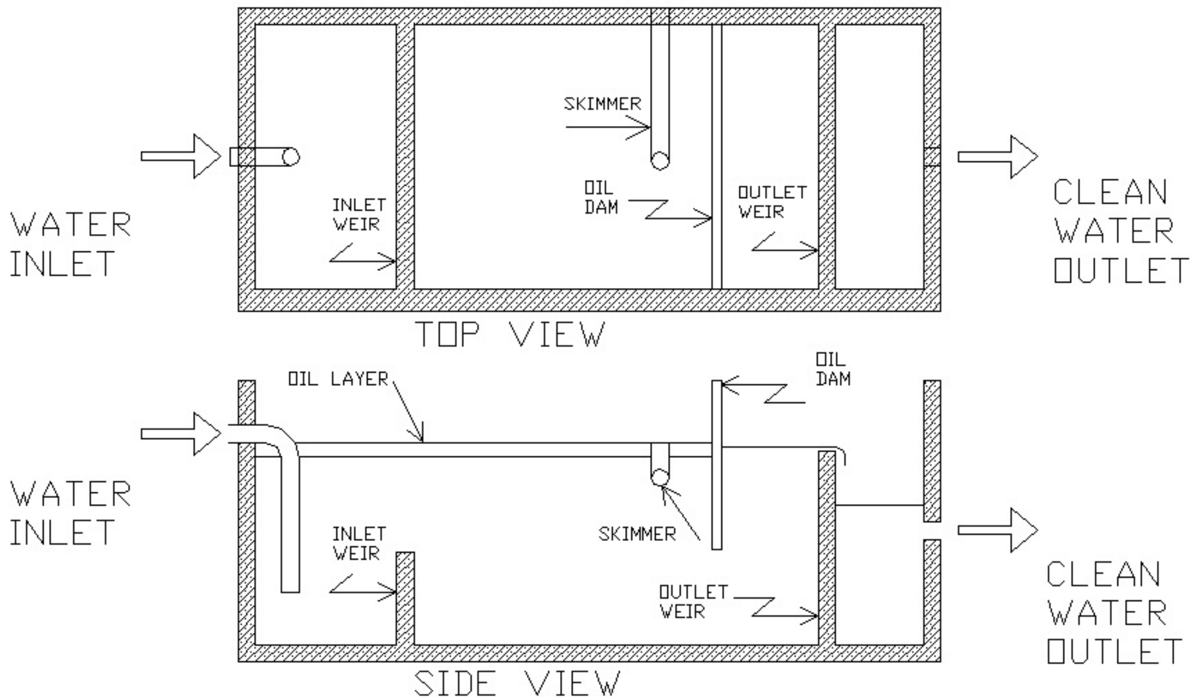

Figure 6: Typical API Separator Design

The API separator has successfully been used in refineries for many years. It is much more effective than simple holding ponds or spill control separators. Advantages of the spill control separator and API separator are simplicity of design, low cost, low maintenance, and resistance to plugging with solids. The primary disadvantage of these simple gravity separators is the poor quality of separation that they provide.

It should also be noted that the design method for API separators mentioned above requires approximately a 45 minute residence time and many separators which are utilized as "API type" do not include enough volume to provide the 45 minutes residence time required.

Figure 7: Typical API Separator, Left Flow Away from Camera, Right Flow towards Camera.

Enhanced Gravity Separation

Enhanced gravity separators provide better separation quality than is possible with simple gravity separators while maintaining the low capital and maintenance cost benefits of the simple systems. In many ways, the enhanced gravity separators substitute sophisticated design for the settling time provided in pure gravity separators. These enhanced gravity separation systems have some similarity to API separators, but include additional internal features that enhance the separation of oil and water. These internal features are basically a substitute for the additional residence time provided by the API separators.

Designs that have successfully been used are:

1) Coalescing plate separators
    a. Inclined plate separators
    b. Horizontal Sinusoidal (flat corrugated) plate separators
    c. Multiple angle separators
2) Coalescing tube separators
3) Packing type separators

Coalescing plate separators:

Inclined plate separators

Inclined plate separators have been used successfully for many years. These systems are usually made in large modules constructed of fiberglass corrugated plates packaged in steel or stainless steel frames. The oil droplets entering the system rise until they reach the plate above, then migrate along the plate until they reach the surface. Plates in this type system are often 3/4" apart, but may be as much as 4" apart. These separators are also known as CPI (corrugated plate interceptor) separators.

Advantages of this system include improved efficiency at removing both solids and oil (over API type separators) and resistance to plugging with solids. Figure 7 shows a schematic of a typical inclined plate separator.

Separators of this general type may be configured in several orientations, with the flow perpendicular to the plates as shown below, parallel to the plates in upflow manner and parallel to the plates in downflow manner. The design varies with the manufacturer and exact service required.

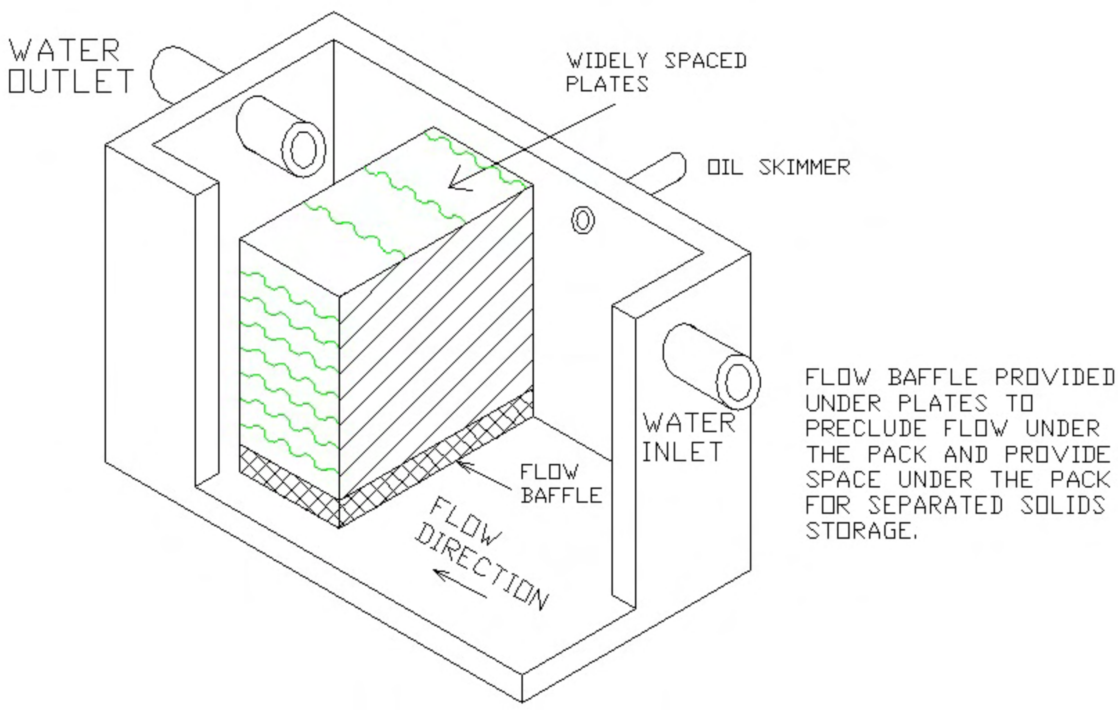

Figure 8 Inclined Plate Separator

Flat Corrugated (Horizontal Sinusoidal) Plate Separators

Flat corrugated plate separators often use horizontal oleophilic polypropylene plates stacked one on top of another in vertical stacks and fastened into packs with rods or wires. Figure 9 illustrates a drawing of a typical flat corrugated plate separator system.

The system uses a combination of laminar flow coalescence and oleophilic attraction. Slowing the flow of water to low velocities where laminar flow regimes exist minimizes turbulence. Turbulence causes mixing of the oil and water and reduces oil droplet sizes. Stokes's law states that larger droplets will rise faster and thus separate better. The oleophilic nature of the plates allows the oil droplets to attach and encourages them to coalesce into larger ones which will rise faster.

These plates provide better separation than could be arrived at without plates. The advantages of this system are that the plate packs are modular and relatively small in size compared to the inclined plate modules. Corrugated plates in this type system are spaced a nominal 0.25" to 0.5" apart. Because the plates are corrugated, rise distances of droplets in the vertical direction are greater than the perpendicular distance between plates. The oil droplets must rise approximately 0.4" for the nominal 0.25" spacing and 0.7" for the nominal 0.5" spacing. Because spacing varies slightly due to variations in plate molding and assembly the spacings are referred to as nominal 0.25" and 0.511 while varying somewhat from these dimensions. Figure 9 provides a detail of part of a separator pack and includes a graphic depiction of rise distances. Because the vertical rise distance to be covered is less than for the inclined plate systems, the same size particle is separated in less time. Conversely, the same amount of space time provided within the plate area causes effective separation of smaller size particles.

Disadvantages of this system are possible plugging of the plate packs by solids and possible damage to the plates by solvents that could attack the polypropylene plates. Plates placed vertically help to alleviate plugging by solids, but do not coalesce as effectively.

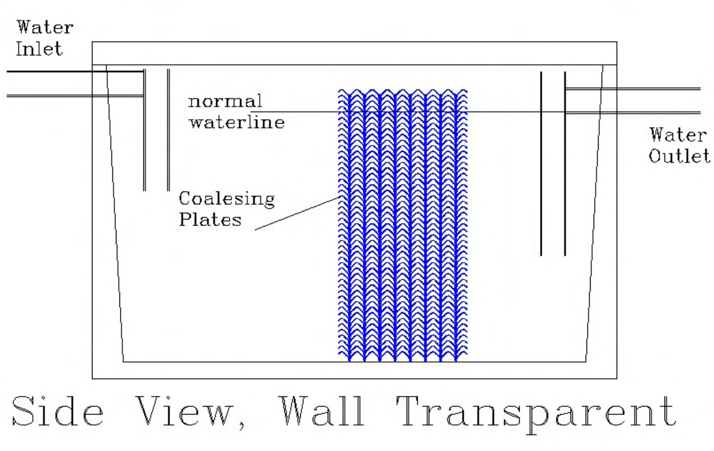

Figure 9: Flat Plate Separator, Left: Schematic Right: typical vault with cover removed.

Multiple Angle Plate Separators

Multiple angle plate separators were developed to take advantage of the virtues of the horizontal sinusoidal separator plates while eliminating many of the disadvantages. The plates are corrugated in both directions, making a sort of "egg-carton" shape. Spacers are built into the plates for two spacings (nominal 0.25" and 0.5", or 8 mm and 16 mm). Figure 10 shows a picture of a typical multiple angle plate pack assembly.

Advantages of the multiple-angle system are:

The plates are designed to shed solids to the bottom of the separator, avoiding plugging and directing the solids to a solids collection area. In inclined plate systems, solids must slide down the entire length of the plates whereas in the multiple angle systems the solids only have to slide a few inches before encountering one of a multitude of solids removal holes. The solids drop directly to the bottom of the separator.

The double corrugations provide surfaces that slope at least a forty-five (45) degree angle in all directions so that coalesced oil can migrate upward. The holes in the plates that constitute the oil rise paths and solids removal paths also provide convenient orifices for insertion of cleaning wands.

The advantages of the aboveground units are that they are factory fabricated and require a minimum of field installation time. Most large units are designed utilizing plates installed in in-ground vaults. The primary advantages of vault installations are that the cost per unit flow is minimized and the below-grade installation is both convenient for gravity flow applications and does not waste valuable plant area.

A typical large underground vault system utilizing multiple angle plates is shown below during installation at a facility in Canada.

Figure 10: Typical Vault Utilizing Multiple Angle Plates
(Photo courtesy Langley Concrete, Langley BC)

ARC PLATES

A compromise between flat corrugated and multiple angle plates, “arc” plates are often used in stormwater processing and industrial applications. Their operation is very similar to both the horizontal plates and multiple angle plates. Figure 11 below shows industrial systems which utilize ‘arc” plates.

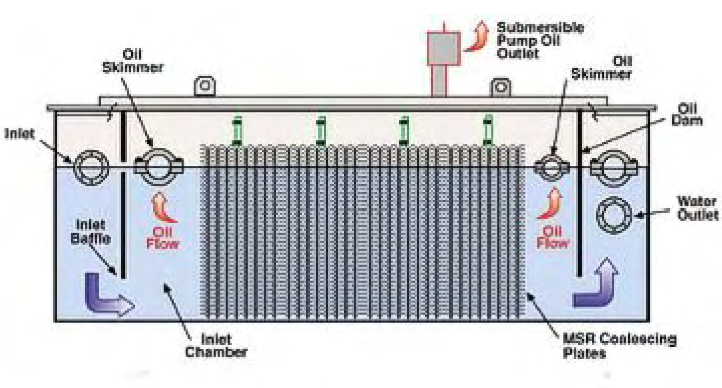

Figure 11: Left: Industrial system with Arc Plates, removes both heavy and light hydrocarbons. Right: Light hydrocarbon removal system for an asphalt processing plant.

Coalescing tube separators:

Coalescing tube separators utilizing perforated plastic tubes for separation have been used for separation of oil and water. The advantages of the use of this type separator are low cost and enhanced separation due to the oleophilic nature of the packing. The disadvantage is that the oil separation from the tubes is more or less random and therefore not optimized. These separators are usually made with the tubes in the vertical position but some are constructed with the tubes horizontal. Operation of the two designs is substantially the same. Figure 12 shows a drawing of a coalescing tube separator and Figure 13 a coalescing tube bundle after use..

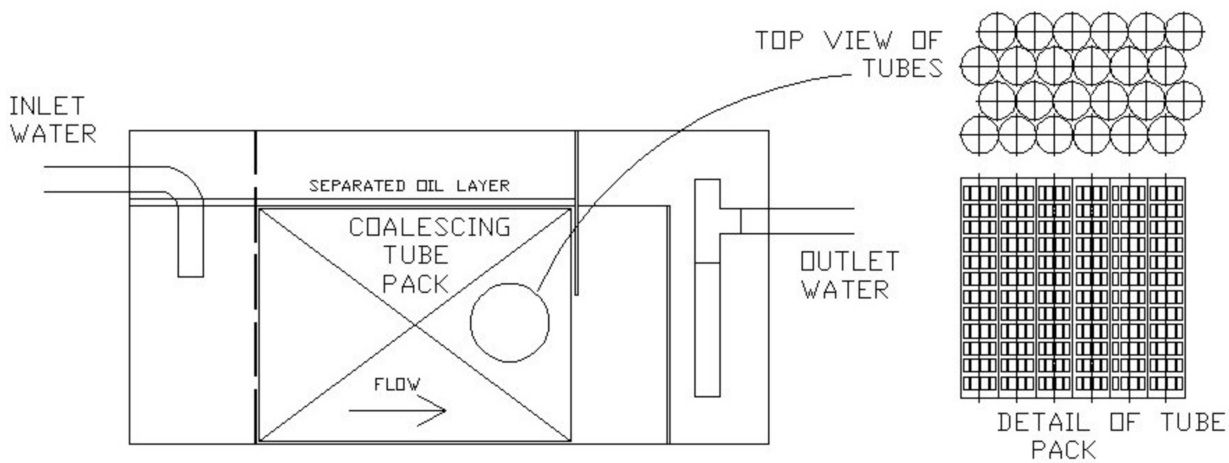

Figure 12: Coalescing Tube Separator

Figure 13 Coalescing Tube Bundle

Packing type separators:

One other system that can be used for coalescence is routing the emulsion through a bed of packing[10]. Experimental data indicates that most of the coalescence occurs in the first few inches of excelsior. This type of coalescer is often used in conjunction with gravity separation or inclined plate separation as a polishing stage. Similar packs have been made of other materials, including stainless steel and polypropylene. Systems of this type can be efficient, but the tightly packed coalescing media can experience plugging problems. Coalescing media of this type is often used as a second stage after a plate type first stage of separation. In this type application, it is common to use plastic woven mesh of the type often used as demister pads in distillation columns. Figure 14 is an illustration of this type separator.

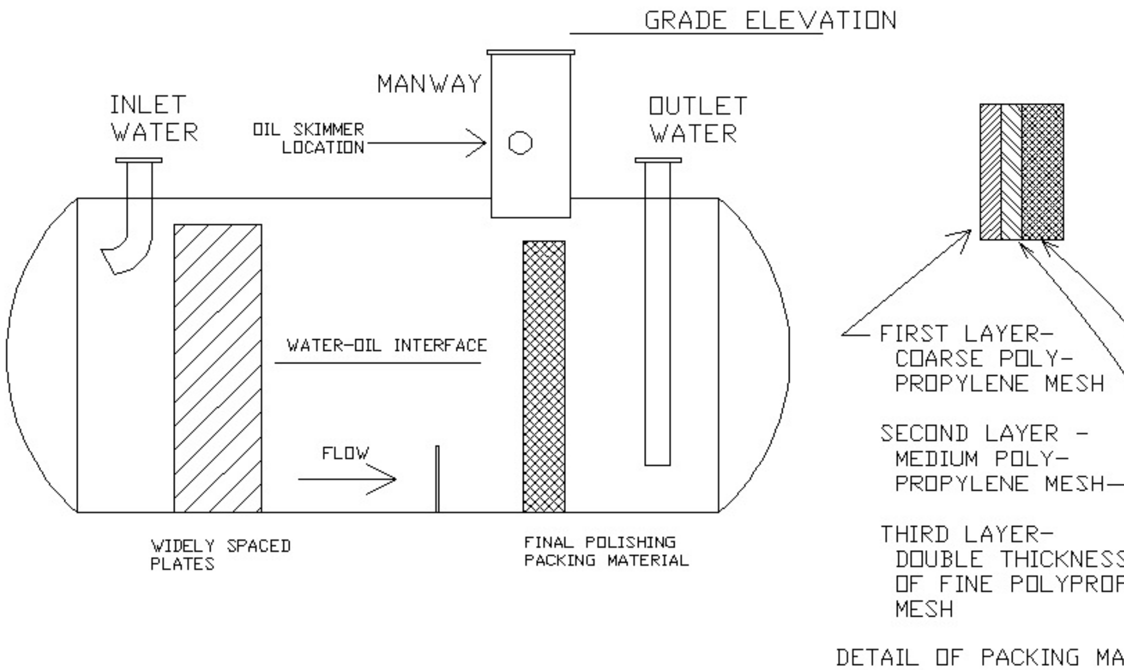

Figure 14 Packing Type Separator

DISSOLVED AIR FLOTATION (DAF) SYSTEMS

Another treatment device for oil removal is the conventional dissolved air flotation (DAF) system. In the DAF process, a portion of the effluent from the DAF is pressurized and air is injected into the recycle stream. The air-laden recycle stream passes through a backpressure valve and then is mixed with the raw influent. Once the pressure is released on the recycle stream, the air comes out of solution in the form of tiny bubbles, many in the range of 40-80 microns. These tiny bubbles attach themselves to particulate matter in the wastewater and the buoyant force on the combined particle and air bubbles is great enough to cause the particle to rise to the surface. In this way most oil droplets in the stream are captured.

While these systems are very effective at removing oil and particulates, they are very expensive compared to gravity systems, both in capital costs and operating / maintenance costs.

INDUCED AIR FLOATATION SYSTEMS:

Induced Air Flotation (IAF) systems are similar to DAF systems in operation except they use induced air instead of air this dissolved and allowed to come out of solution.

A typical IAF unit would include a pump-like device mounted vertically in a tank with the motor above the water and the diffuser disc below. The diffuser disc incorporates fine holes near its perimeter for ultra-fine bubble diffusion into the liquid. The motor turns the diffuser disc at a high speed, creating a low-pressure zone at the disc's diffuser ports, which draws air, or gas, from above the liquid surface. That air, or gas, then proceeds down through the draft tube, into the disc and out of the submerged diffuser ports. Each bubble exits through a hole in the edge of the diffuser disc. The spinning disc shears it into microscopic air bubbles measuring from 10-100 microns in diameter. These air bubbles adhere to minute solids such as oil and grease. The bubbles slowly rise to the surface around the unit, bringing the solids to the surface.

These units have the same general advantages and disadvantages as DAF systems but are somewhat less complicated.

EXOTIC SYSTEMS:

Reverse osmosis membranes and other exotic means of removing oil from water are sometimes used. These units are usually too expensive to be used for wastewater treatment.

HYDROCYCLONES AND OTHER CENTRIFUGAL DEVICES

Hydrocyclones are used in situations where there are extremely high solids loadings that would plug other equipment or where there is a high pressure water stream that needs to be at a lower pressure. They have high operating costs if there is not a free pressure drop available because they require a lot of energy input to operate. They are also flow rate sensitive and do not operate well at much below 90% of the design flow rate.

Other centrifugal devices (usually called "swirl" devices) have been offered as stormwater processing equipment. These evidently remove some grit and other debris, but do not do much to remove oil. Testing on one such system in the UK[11] indicated an effluent of about 60 mg/l of oil which would not meet the requirements of the US Clean Water Act.

ABSORBENT SYSTEMS:

Another expensive but effective means of removing residual oil in water is the use of activated carbon or other absorbents such as polyester or polypropylene fibers, sawdust, and . Carbon is sometimes used as a polishing step, but can be prohibitively expensive if the first stages are not effective.

The advantage of the use of absorbents is that it is possible with their use to get to non-detectable levels of hydrocarbons in the effluent water. In addition, no other equipment is usually needed – absorbents are simply thrown on the water to absorb the hydrocarbons.

The problems with their use are that, on a per pound of hydrocarbon removed from the water, they are very expensive and because they are readily used up, they are usually not changed frequently enough. The result can be that there is no system at all to remove the oil from the water.

SELECTION AND DESIGN OF OIL-WATER SEPARATOR SYSTEMS

General Design Considerations

Numerous factors must be considered in the selection and design of oil-water separation systems. Among these are:

1. Flow rate and conditions
2. Degree of separation required - effluent quality
3. Amount of oil in the water
4. Existing equipment
5. Emulsification of the oil
6. Treated water facilities
7. Recovered oil disposal method

For industrial and some municipal applications, flow rate, amount of oil, flowing temperature, and other conditions affecting separation such as whether flow is laminar or turbulent may be easily determined. The degree of separation required is usually a matter of statutory or regulatory requirements, but if the water is discharged to a sanitary sewer plant or industrial treatment plant it may be negotiable.

The amount of oil in the water may be known, especially in industrial applications, but it will often be necessary to estimate the quantity in stormwater applications. Equipment manufacturers can provide guidance about quantities to be expected, and some information has been published about stormwater quality [7],[6], [17], and [15].

Existing equipment such as API separators may affect the design of equipment to be used. Often it is possible to retrofit existing equipment with more sophisticated internals to enhance separation quality. The degree of emulsification of the oil is difficult to assess, but steps can be taken to discourage the formation of emulsions and encourage the breakup of emulsions that are inadvertently created. It may be necessary to substitute quick-break detergents for conventional detergents that are also emulsion causing. Quick-break detergents are those detergents designed to remove the oil (or grease) from the item to be cleaned and then quickly dissociate again from the oil, leaving the oil as free hydrocarbon droplets in the water.

It is necessary to ensure that adequate size piping is provided for downstream treated water removal to avoid flooding the separator and perhaps filling the oil reservoir with water. A downstream test point should be provided to allow for effluent testing. Adequate storage facilities for the removed oil should be provided and means for recycling the oil included. Careful records of removed and recycled oil should be kept to avoid possible future regulatory problems.

INTRODUCTION TO SEPARATION OF OIL AND WATER

by Kirby S. Mohr. P.E.

The following is a discussion of several of the points touched briefly on above concerning design of oil-water separation systems.

Influent Conditions

Much of the performance of an oil-water separator depends on the influent conditions. Because smaller droplets are more difficult to separate, equipment or conditions that form small droplets in the influent to the oil-water separator will cause the separator to be designed larger to accommodate the additional time required for the smaller droplets to coalesce. Conditions that form small droplets are any conditions that cause shear in the incoming water. The following are (more or less in order of severity) some factors that can cause small droplet sizes.

1. Pumps, especially centrifugal pumps
2. Valves, especially globe valves
3. Other restrictions in flow such as elbows, tees, other fittings or simply unduly small line sizes
4. Vertical piping (horizontal is better). Emulsifying agents as discussed elsewhere in this paper greatly contribute to small droplet sizes in addition to discouraging coalescence.

Ideal inlet conditions for an oil-water separator are:

1. Gravity flow (not pumped) in the inlet piping
2. Inlet piping sized for minimum pressure drop
3. Inlet piping straight for at least ten pipe diameters upstream of the separator (directly into nozzle)
4. Inlet piping containing a minimum of elbows, tees, valves, and other fittings.

Most separators are provided with an inlet elbow or tee inside the separator pointing down. This is an exception to the above rules and is intended to introduce the influent water below the oil layer on the surface, thus not disturbing the surface oil and re-entraining some of it.

While gravity flow conditions are not often obtained except in sanitary sewer facilities, stormwater, or some process water applications, a positive displacement pump such as a progressive cavity type pump may be used as they provide minimum disturbance of the fluid.

Inlet piping should be as smooth as possible to avoid turbulence caused by pipe Toughness. Smooth PVC is preferable to rough concrete.

Sometimes anti-emulsifying chemicals are utilized, but extreme care must be exercised in the use of these chemicals to ensure that they do not make the emulsion worse instead of improving it.

If large quantities of solid particles are expected, it is wise to provide a grit removal chamber before the separator. These chambers should be designed according to normal design parameters for grit removal as used in sanitary sewer plant design.

Effluent Conditions

Effluent designs are also important in the operation of oil-water separators. Downstream piping and other facilities must be adequately sized to process the quantity of water (and oil) from any likely event. Manholes overflowing during a heavy rainstorm will surely cause any oil that has accumulated to be re-released into the environment.

Effluent piping must be designed with siphon breaks so that it is not possible to siphon oil and water out of the separator during low flow conditions. One way to do this is to provide the sampling/overflow tee in the effluent line as shown in Figure 5. If the effluent arrangements are not properly designed, a vortex from the effluent pipe can "reach up" to the interface and cause discharge of oily effluent water even if the interface is clear [4]. Oil must be removed manually from spill control separators by a maintenance crew equipped with a vacuum truck or other equipment for oil removal. If this is not done on a regular basis, this oil may become re-entrained at the next rainfall event and reintroduced into the environment.

Removing the oil from the separators is not enough to protect the environment; it must also be recycled to ensure that it is disposed of properly. Current U.S. law can hold the owner of the oil-water separator responsible if this oil is not properly disposed of, even if the owner has paid for proper disposal.

SUMMARY AND CONCLUSIONS

Environmental regulations are steadily becoming more restrictive and requiring lower concentrations of hydrocarbons in effluent water. The EPA's new stormwater regulations require treatment of stormwater not currently treated. Some localities require lower effluent standards than even the EPA mandates.

Unfortunately budgets for wastewater treatment are always very limited, so it is becoming necessary to provide more effective treatment without increasing capital and operating costs.

Fortunately, engineering advances are being made that will help to alleviate the problem of having to provide very costly treatment systems. One of the best ways to ensure regulatory compliance is to provide a complete computer simulation of the wastewater treatment system. A proper simulation will allow the engineer to choose a system that meets the requirements without undue over-design and additional cost.

Sometimes treatment systems can be as simple and inexpensive as spill control separators. In rare cases, it may be necessary to provide costly, elaborate, methods of treatment such as reverse osmosis systems. The most appropriate method of treatment is the least expensive method that provides the required effluent quality.

Reference List

1. *Waste Water Handling and Treatment Manual for Petroleum Marketing Facilities - Publication 1630*, American Petroleum Institute. American Petroleum Institute, 1979.

2. American Petroleum Institute. "Design and Operation of Oil-Water Separators, Publication 421." *Design and Operation of Oil-Water Separators, Publication 421*, American Petroleum Institute. American Petroleum Institute, Washington, D.C., 1990.

3. Au, K. K., C. L Tiller, C. R. O'Melia, and R. F. Schmidt. "Oil/Water Separation: Modeling and Evaluation." Oil/Water separation: modeling and evaluation *WEF Annual Conference*1992.

4. Bansbach, Paul L. "The How and Why of Emulsions." *Oil and Gas Journal* 68, no. 36 (1970): 87-93.

5. Findley, R. W., and D. A. Farber. " *Environmental Law in a Nutshell*. St. Paul, MN: West Publishing Co., 1992.

6. Hoffman, Eva J., James S. Latimer, Gary L. Mills, and James G. Quinn. "Petroleum Hydrocarbons in Urban Runoff From a Commercial Land Use Area." *Journal WPCF* 54, no. 11 (1982): 1517-25.

7. Hunter, J. V., T. Sabatino, R. Gomperts, and M. J. MacKenzie. "Contribution of Urban Runoff to Hydrocarbon Pollution." *Journal WPCF* 51, no. 8 (1979): 2129-38.

8. Jackson, David E., and Jack C. Scott. "What You Should Know About Electrostatic Coalescing." *Petro / Chem Engineer* (1961).

9. James M. Montgomery, Inc. *Water Treatment Principles and Design*. New York, NY: John Wiley and Sons, 1981.

10. Love, Forrest E. "Oil-Field Emulsions...How to Make and Break Them." *Oil-Gas International* (1948).

11. Pratt, C. J. *Laboratory Tests on X-Ceptor Concrete Bypass Interceptor (Also Known As Stormceptor in North America)*, Coventry, UK, 1996.

12. Romano, Fred. *Oil and Water Don't Mix: The Application of Oil-Water Separation Technologies in Stormwater Quality Management*, Office of Water Quality, Municipality of Metropolitan Seattle , Seattle, WA, 1990.

13. Rommel, Wolfgang, Eckhart Blass, and Walter Meon. "Phase Separators for Dispersed Liquid-Liquid Systesm: Multiphase Flow, Droplet Coalescence, Separation Performance and Design." *Chemical Engineering Science* 47, no. 3 (1992): 555-64.

14. Smith Industries. *Equipment Manual, Oil and Gas Division*, Smith Industries, Houston, Tx, 1980.

15. Stenstrom, Michael K., Gary S. Silverman, and Taras A. Bursztynzky. "Oil and Grease in Urban Stormwaters." *Journal of Environmental Engineering ASCE* 110, no. 1 (1984): 58-73.

16. Stokes, George Gabriel. *Transactions, Cambridge Philosophical Society* 8, no. 287 (1845).

17. Wakeham, Stuart G. "A Characterization of the Sources of Petroleum Hydrocarbons in Lake Washington." .*Journal WPCF* (1977): 1680-1687.